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# SPECIFICATION

## SYSTEM AND METHOD FOR MACHINING BODY PARTS, WHEREIN ROBOTS ARE SYNCHRONIZED WITH A CONVEYOR BELT

The present invention pertains to a machining process and a machining plant, especially a joining plant with the features described in the preambles of the principal process claim and of the principal device claim.

Such joining plants for manufacturing body shells are known from practice. They comprise a cyclically operating conveyor for the workpieces, which is designed, e.g., as a lifting shuttle. The joining plant is divided here into a plurality of stations, which are arranged along the conveyor or transfer line and in which different joining tasks are performed by robots on the stationary workpiece, the robots being arranged stationarily in the stations on one or more sides of the transfer line. This design has the drawback that a relatively large number of robots is necessary, and the robots as well as the tools are not utilized optimally. Due to the binding to stations and working on the stationary workpiece, there is a fixed binding to the cycle time, and, in addition, the robots have a limited working range only. The overall cycle of the joining plant also includes, besides the working time, the conveying time as an appreciable component, which adversely affects the efficiency. Furthermore, there is an increased distance between the robots at the transitions from one station to another due to the binding to stations, which increases the space requirement. Since

the robots machine only partial areas on the stationary workpiece, a plurality of robots and also a plurality of tools of the same type must be used for tasks of the same kind on the front and rear sides of the workpiece.

Assembly on moving bodies is known from DE 195 20 582 C1. The assembly robot is moving in this case along an additional travel axis in the conveying direction, synchronously with the body, and is coupled with the body conveyor for this purpose. After the end of the assembly job, the robot must be returned into its starting position. This leads to increased space requirement in the conveying direction. Moreover, it is not possible to line up a plurality of robots at closely spaced locations next to one another in the conveying direction.

DE 35 16 284 A1 likewise pertains to the performance of assembly operations on a moving vehicle body. Assembly robots with an additional linear axis, which move synchronously together with the vehicle being conveyed and must be returned after the completion of the job, are present here as well.

DE 199 31 676 C2 teaches the measurement of a body; which is stationarily resting during the measuring operation. The measuring robot has an additional linear axis, with which it can change its basic working position. It must be zeroed again at the new measurement site on the basis of stationary calibration marks.

DE 101 36 691 A1 pertains to the compensation of position errors of a robot by means of a laser measuring instrument. This is only a calibration operation. In addition, a welding tool and a

workpiece can also be measured and calibrated with the measuring instrument, which simplifies and expedites the calibration operation.

DE 24 30 058 A1 discloses a position measuring system for robot members and is used to measure and calibrate a robot with compensation of its axis error.

The object of the present invention is to show a better machining process along with a machining plant and especially a joining plant for manufacturing body shells.

This object is accomplished by the present invention with the features described in the principal claim.

Higher efficiency and better utilization of the robots used and their tools can be achieved with the claimed process and the joining plant, which is designed, e.g., in the preferred embodiment, as a so-called robot welding plant. The binding to stations can also be eliminated. The space requirement and the design effort are reduced. The number of robots used can be minimized because of the fact that their working range is enlarged in terms of function and in space.

The rigid binding to a cycle time can be eliminated by the continuous conveyors and the machining of the workpieces during the movement of the conveyor. The output of the joining plant is increased. The robots can be optimally positioned corresponding to their function and their machining tasks. Unnecessary free spaces, as they were present in case of the prior binding to stations, can be avoided. The space requirement of the joining plant decreases correspondingly.

A suitable sensor system for detecting the movements and the positions of the workpieces, which cooperates with a control system, which is, for example, a higher-level control system or a control system integrated in a robot control, is present for the synchronization of the preferably stationarily arranged robots with the conveying movement of the workpieces. As a result, the conveyor and the robots can be controlled and synchronized centrally. A monitoring system, which monitors compliance with the synchronization in the working range of the robots and optionally ensures the adjustment of the conveying movement and/or the movement of robots, is preferably present as well.

Additional advantageous embodiments of the present invention are described in the subclaims.

The present invention is schematically shown in the drawings as an example. Specifically,

Figure 1 shows a schematic view of a machining plant with a central control system,

Figure 2 shows an enlarged top view of the joining plant according to Figure 1,

Figures 3 and 4 show functional views of a detail of the joining plant according to Figure 2 with synchronized robots,

Figure 5 shows a variant of the joining plant according to Figure 2, and

Figure 6 shows a joining plant according to the state of the art.

Figure 6 shows a machining plant 1 for manufacturing body shells in a design according to the state of the art known from practice. The machining plant 1 is designed as a joining plant for manufacturing body shells, especially as a respot welding plant for vehicle body shells or body shell components. It is divided into a plurality of stations A through D arranged one after another along a transfer line 3. The vehicle body shells 2 are conveyed from one station to the next by means of a conveyor 5 overlying the plant. This is a cyclically operating conveyor, e.g., a lifting shuttle. A working cycle that is preset in a fixed manner and is divided into machining times and conveying times, applies to the entire joining plant 1. One or more stationary robots 7, 8, which join the bodies 2, which are stationary during the machining, e.g., weld them by means of spot welding tongs or other welding tools, is/are arranged within the stations A through D on one side or on both

sides of the transfer line 3. The robots 7, 8 have working ranges limited in space at the body 2, one robot 7,8 working in the front area of the body on each side and another robot 7, 8 working in the rear area of the body. The tools, especially welding tools, must be correspondingly present as a plurality of tools for activities of the same kind, e.g., spot welding.

A free space is usually left between the individual stations A through D, the adjacent robots 7, 8 having a greater distance  $d$  in this area than within the individual stations A through D. The prior-art joining plant 1 with the station concept therefore requires a considerable amount of space in the transfer direction and its efficiency is not optimal due to the strict working cycle.

Figures 1 through 5 show a machining plant 1 according to the present invention, especially in the form of a joining plant and especially a respot welding plant. One or more conveyors 5, which are designed as continuously operating conveyors and convey the workpieces 2, especially vehicle body shells or body parts, in a continuous and preferably steady movement in the conveying direction 4, are used in the joining plant 1.

The conveying movement may be adjusted to a constant velocity. As an alternative, the conveying velocity may vary locally and be accelerated or decelerated at individual conveyors 5 in case of the use of a plurality of conveyors 5. As a result, the distances between the workpieces 2 may change locally (so-called "breathing" of the workpieces). An increase in the distance creates, e.g., space in the front and rear areas for machining operations to be performed there. The original distance is then restored by a subsequent deceleration.

The workpieces 2 may be arranged directly on the conveyor 5. As an alternative, they may also be held on carriers, especially pallets 6, in a predetermined position and clamped and conveyed with these carriers 6.

The individual conveyor 5 may be a one-part conveyor. As an alternative, it may also be divided into a plurality of conveying sections. The conveyor or the conveying sections have suitable controllable drives each, which are schematically shown as motors in Figure 1. The conveyor 5 may have any desired suitable design as a roller type conveyor, chain conveyor or the like.

The robots 7, 8 machine the workpieces 2 being conveyed during their conveying movement. The robot movements can be synchronized with the conveying movement for this purpose. The robots 7, 8 are controlled now as a function of the position and the velocity of conveying of the workpieces 2. The joining plant 1 has a suitable sensor system 13 for this purpose for detecting the movements and the positions of the workpieces 2 and/or their carriers 6.

The robots 7, 8 are designed as stationary articulated arm robots, which remain stationary with their base at the bottom during the activity. The robots 7, 8 have a plurality of rotatory axes, preferably six axes. They are designed, e.g., as industrial roots, in which a carrousel rotates around the first vertical axis I on the stationary base, and a rocker is mounted pivotably around a horizontal second axis II at the carrousel, and an extension arm at the end of the rocker is mounted pivotably around a horizontal third axis III. The extension arm carries at its end a multiaxial robot hand, preferably a so-called central hand with three intersecting rotatory axes IV, V and VI. The above-mentioned synchronization with the conveying movement is brought about by changes in the rotary

movements of the rotatory axes, which are usually multiaxially superimposed to one another.

In addition, a monitoring means 11 is present in order to monitor compliance with the synchronization during the process. The monitoring system 11 may have, e.g., one or more means, especially cameras, for optical imaging and evaluation for this purpose. It can be determined from this, e.g., whether the robots 7, 8 with their tools 10, synchronized with the conveying movement, are indeed being moved synchronously with the workpiece 2 during the joining operation and/or during their feed and resetting motions. In addition, any imminent collisions between tools 10 and interfering edges on the workpiece 2 can be detected. The collision-free mutual coordination of adjacent robots 7, 8 can be monitored as well.

Compliance with the synchronization can also be monitored during the joining process in another way, e.g., by force measurement at the robot 7, 8 and/or at the tool 10. If the movement of the robot is not synchronous with the conveying movement, a relative movement develops, which is manifested in a change in the forces acting in the process, which affect, in turn, the robot axes and can be detected there by monitoring the torques or the power of the axle drives or in another manner, e.g., by means of force and torque sensors.

The robots 7, 8 have a specific machining program stored preferably in their robot control for their operations to be performed at the workpiece 2. This may be, e.g., a machining program programmed for static operation at the stationary workpiece 2, to which a dynamic component corresponding to the conveying movement is superimposed during the execution. It is possible to respond to possible changes in the velocity of conveying or even in the position of the workpieces 2



immediately and on-line in this superimposition. As an alternative, the machining program may already contain the dynamic component and be programmed for a certain conveying movement. Whether the preset dynamic conditions are met or whether an on-line adjustment is necessary is monitored during the synchronization in this case.

The joining plant 1 has at least one control system 12, which is preferably central and overlies plants. All the robots 7, 8 present in the plant 1 are preferably connected to the control system 12. The sensor system 13, the monitoring system and the drives of the conveyor 5 or of the conveying sections are preferably also connected to the central control system 12. To comply with the synchronization, it is possible to use the conveying movement and especially the position and the velocity of the workpieces 2 as a preset value, the working and feed motions of the robots 7, 8 being correspondingly synchronized. The conveyor 5 may also be adjusted to a preset value, especially if the robots 7, 8 already store dynamized machining programs in their control.

A station 14 in which the conveyor 5 or the carrier 6 is loaded with workpieces 2 may be arranged upstream of the joining plant 1 on the input side. Furthermore, clamping functions may be performed in this station 14 by actuating, e.g., tension jacks on the carrier 6 by connecting corresponding energy and control connections. These energy and control connections can again be disconnected during the conveying through the plant 1. The station 14 is preferably also connected for this purpose with the central control system 12 via a corresponding control component. Finally, checking operations may also be performed in the station 14 in order to check the workpiece 2 for correct positioning on the conveyor 5 or on the carrier 6 as well as the tension jacks and possibly other machine components for correct function.

A similar station 15, on which the machined workpieces 2 are unloaded from the conveyor 5 or the carriers 6, may be present on the output side of the joining plant 1. Checking operations may also be carried out here once again to finally check compliance with the correct tensioned position of the workpieces 2 during the preceding passage through the plant and optionally also to carry out a quality control of the joining operations carried out in the plant 1.

Figure 5 schematically shows a variant of the joining plant 1 according to Figure 2. In Figure 2, the robots 7, 8 are arranged on both sides of the transfer line 3, and the workpieces 2 pass through the plant 1 only once and in one direction. In the variant according to Figure 5, the workpieces 2 are moved in a loop or a circle through a correspondingly designed conveyor 5. Robots 7 are arranged now on one side of the transfer line 3 only, and these robots are, moreover, located, between the two transfer lines 3 formed by the loop or the circle. The robots 7 now machine the right-hand side of the vehicle parts 2 during their forward motion and their left-hand side during their return motion. The robots 7 may work alternatingly from the front and from behind.

Figures 3 and 4 show a schematic view of the synchronized robot operations. As is illustrated in Figure 3, the robot 7 at first machines the rear area of the workpiece 2 located in the front in the conveying direction 4 with its tool, not shown, by welding, e.g., a plurality of weld spots there with spot welding tongs. As soon as the operation is completed or the workpiece 2 leaves the working area 9 of the robot 7, the robot 7 pivots back into the position indicated by broken line and machines the next workpiece 2 following at a distance, performing machining operations on the front side of the workpiece. The robot 7 can consequently machine different areas of the workpiece 2 being moved past it with correspondingly different processes.

The machining operations take place in any desired movement along a path in space, the robot hand and the tool being moved multiaxially. The synchronization of the movements of the robots 7, 8 along the axes is likewise multiaxial. Contrary to pure assembly operations, e.g., the lateral mounting of wheels on the vehicle, in which the robot must move the independently movable tool, e.g., a mechanical screwdriver, with only simple kinematics on a straight path synchronously along the conveying direction and the tool performs the transversely directed mounting operations itself with a drive of its own and without the need for robot axes, a substantially more complicated kinematics is required in the case of these complex machining operations and the optimized interaction of a plurality of robots 7, 8 standing next to each other. The robot movements and their synchronization depend on the needs of the process and the component.

A machining path extending at right angles or obliquely in relation to the conveying direction and possibly also with a vertical component, e.g., a weld seam or bonded seam, weld spot line, etc., requires a changed synchronization of the movements along the axes during the following of the path with a robot-guided welding tool each time there is a change in direction. This goes beyond a pure straight guiding along the conveying direction because the path followed by the robot 7, 8 and its tool extends in space and with readily varying directions and curvatures.

The robot 7 may also change the tool, if necessary, during the machining. The robot is optimally utilized as a result, and the tools 10 used are also better utilized and their number is optimized. Joining operations of the same kind can thus be carried out by one robot 7 on the entire side of the workpiece 2 that moves past it and faces it. The robot 7 may place, e.g., all or at least a majority of the weld spots on the right-hand side of the vehicle body 2 in Figure 3.

As is illustrated in Figures 1 and 2, the robots 7, 8 are arranged essentially at equal distance from one another along the transfer line 3. The working ranges of the robots 7 at the workpieces 2 can be enlarged now compared with prior-art plants, so that fewer robots 7, 8 are needed. The distance between the robots 7, 8 along the transfer line 3 can be optimized and set according to the needs of the process. There are no longer any rigid dimensions and binding to specific distances, as in the case of the state of the art according to Figure 6. In addition, the binding to stations is preferably eliminated in the joining plant 1 according to the present invention, so that the safety and free spaces present before between the stations are dispensable. The robots 7, 8 can be arranged at correspondingly more closely spaced locations from one another. The length of the plant becomes correspondingly shorter.

Figure 4 illustrates in another view the synchronized movement of the robots 7, 8 with the workpiece conveying. The robot 7 welds at first areas on the body shell, e.g., with the workpiece 2 arriving from the left. The robot 7 also rotates around its vertical base axis I during the continuous conveying of the workpiece and possibly also changes the other axis positions, in order to thus place, e.g., a series of weld spots on the body shell. The robot 7 also moves now by corresponding movements along axes synchronously with the body part 2 during the welding operation with the welding tongs closed. The feed motion to the next weld spot likewise takes place synchronously. Figure 4 shows the feed of the body part and the corresponding synchronous adjusting movements of the robot 7 by broken lines and cut-away views. The workpiece 10 is not shown for clarity's sake. The position of the robot 7 is also shown as a cut-away view and partially.

In the preferred embodiment, the robots 7, 8 are arranged stationarily at the bottom and on one side

or on both sides of the transfer line 3 and the conveyor 5. In addition, robots may be arranged at a frame or portal located within the plant 1. In another variant, the robots may have one or more additional axes, e.g., a travel axis directed along the transfer line 3.

Various variants of the embodiments shown are possible. This applies, on the one hand, to the number, arrangement and design of the robots 7, 8. The designs of the conveyor 5 and the sensor system 13 used as well as the monitoring means 11 may also be varied.

The synchronization between the conveying movement and the robot movement may also take place mechanically as an alternative, e.g., by a temporary, optionally articulated towing connection or another mechanical coupling of a suitable robot part, e.g., the front end of the extension arm, with a workpiece 2, a carrier 6 or a moving part of a conveyor 5.

Furthermore, the control system 12, which may also comprise a plurality of individual control components, is variable. In addition, it is possible here to shift the control system 12 entirely or partially into one or more robot controls, in which case the conveyor 5 or conveyors is/are controlled in its/their working range by an individual robot 7, 8 or a group of robots 7, 8. As a result, the conveying movement can be locally optimally coordinated with the needs of the process or the properties of the robot. Furthermore, it is possible to shift the central plant control into a robot control.

## **LIST OF REFERENCE NUMBERS**

- 1     Machining plant, joining plant
- 2     Workpiece, vehicle body
- 3     Transfer line
- 4     Conveying direction
- 5     Conveyor
- 6     Carrier, pallet
- 7     Robot
- 8     Robot
- 9     Working space
- 10    Tool
- 11    Monitoring system
- 12    Control system
- 13    Sensor system
- 14    Loading, clamping and checking station
- 15    Checking and unloading station